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DISCLOSURE TITLE: Phase-Sensitive **Overlay** Analysis Spectrometry.

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DISCLOSURE TEXT:

- Accurate measurements of the **overlay** between structures on, say, semiconductor wafers may be made by spectrometrically analyzing sets of superimposed **gratings**. An algorithm is described which evaluates the symmetric properties of the **gratings**. This allows offset measurements that are largely independent of **grating** profile distortions.

- Computer simulation indicates that an accuracy of some 3% of the **overlay** value + 1 nm can be maintained.

- **Overlay** Spectrometry For the analysis of **grating** pattern depth, computer-based white- light spectrometry may be used. Well-known film thickness algorithms are available for evaluating the interference pattern of the zeroth order of diffraction of the **grating**. Such an interference fringe pattern is produced if two **grating** structures are not perfectly overlapping. If one of the **gratings** is shifted by half a **grating period,** another fringe pattern results. The transition between these patterns is a function of the offset between the **gratings**.

- An example of an **overlay** measurement set-up is shown in Fig. 1.

A group of **four grating** patterns with a diameter of some 10 mm for

each direction is printed with the features whose **overlay** is to be tested. The spectral reflectance of the composite pattern can then be sequentially sensed. Parallel sensing may be done with a multiple spectrophotometer generating **four** spectra along a linear photodiode array. This allows exploiting the larger number of photodiodes (say, 256) of current diode array products, with the moderate spectral resolution requiring less than 50 signal channels per spectrum.

- Model Calculation. The difference between the signal from a sine-shaped pattern and the signal Fkt(x) from a trapezoid was calculated for various values (Fig. 2). This difference defines the maximum **overlay** error that may arise if only limited information is available on the real signal shape. The **grating period** should be selected trading the resolution of the photolithographic process against signal noise. A 2 mm **grating period** may be a good value for a process with a resolution better than 1 mm.
- Three scenarios are discussed below based on the data of Fig. 2.
- 1. There is no information on the shape of the superimposed **gratings,** i.e., the linewidth may have a value of between 600 and 1400 nm for one **grating** and 800 and 1200 nm for the other. The deviation may reach a maximum of 0.08 corresponding to an offset error of about 20 nm. Below 10 nm offset, the maximum deviation may reach some 20% of the offset value. The mean value between x/(0.25-x) and tan(2fx) may be used to decode the offset. This reduces the maximum error to 10%.
- 2. One **grating** is processed to appear with u = 1/f to the meas uring system. u may vary within a range of 5%. This means a linewidth of one **grating** of 600 to 660 nm. The linewidth of the other **grating** may vary between 800 and 1200 nm. In this case, the maximum offset error is only some 3% of that obtained when an appropriate decoding table is used.
- 3. u = 1/f to within 2%, i.e., the linewidth is between 620 and 640 nm and v > 0.4. The maximum offset error is below 1% for offset values of up to 50 nm. Between 50 and 100 nm, the error may

increase to 1.5%.

- Spectrometric Evaluation To increase the signal-to-noise ratio, an averaging procedure across the optical spectrum may be used.
- 1. Spectra are taken at **four** test sites with superimposed **grating** structures. The bias between the **gratings** is increased by one **quarter of the grating period** for successive test sites.
- 2. The spectra of the sites with a half a **period** bias difference are subtracted.
- 3. The values of the "difference spectra" are averaged. To fit the signals into an **overlay** range of 1/4 **grating period,** the corresponding values of the difference spectra are negated according to the sign of one of them. If inversions take place across the spectrum (i.e., for a **grating** depth exceeding the wavelength of light), the signal distortion resulting from an uncontrolled global offset of a spectrum averages out.
- 4. To reduce the signal noise, small values are excluded from the averaging process.
- 5. The smaller of the average values is divided by the larger one.
- 6. A table look-up gives the offset phase value.
- 7. The phase value is placed within the **grating period**. The information for this process is extracted from the relative magnitude and sign of the difference value. The higher fringe density in the spectrum at zero offset allows finding the correct half**-period**.
- 8. Multiplication with the **grating period** gives the offset value.
- To estimate the noise for this procedure, input spectra with 0.5% random and digitization noise are assumed. At a 50% spectrum modulation with zero offset, the noise in the difference spectra is about 1%. Averaging some 50 values in each spectrum reduces the noise to 0.15%. Division and look-up produce the phase with a noise of 0.3% per octant. This allows an offset determination within 0.05%

of a **grating period,** i.e., 1 nm for 2 mm **gratings**.

- If the depth of one **grating** becomes too small (<< 20 nm), the modulation of the difference spectrum decreases rapidly. Additional modulation minima appear when the input spectra have overlapping fringe patterns, for example, with maxima of subsequent interference orders near the center of the spectra.
- Conclusions Offset analysis, using the combination of spectrometric sensing and 4-point evaluation, allows ultimate precision for photolithographic **overlay** measurement.
- Testing of **grating** structures averages local imperfections.
- 4-point evaluation makes offset measurement largely independent of distortions of the **grating** structures. The **overlay** error decreases in proportion to the **overlay** value. Measurement is self-referencing and requires no calibration.
- Spectrometric sensing affords unrestricted measurability, boosts the signal-to-noise ratio and allows half**-period** discrimination.

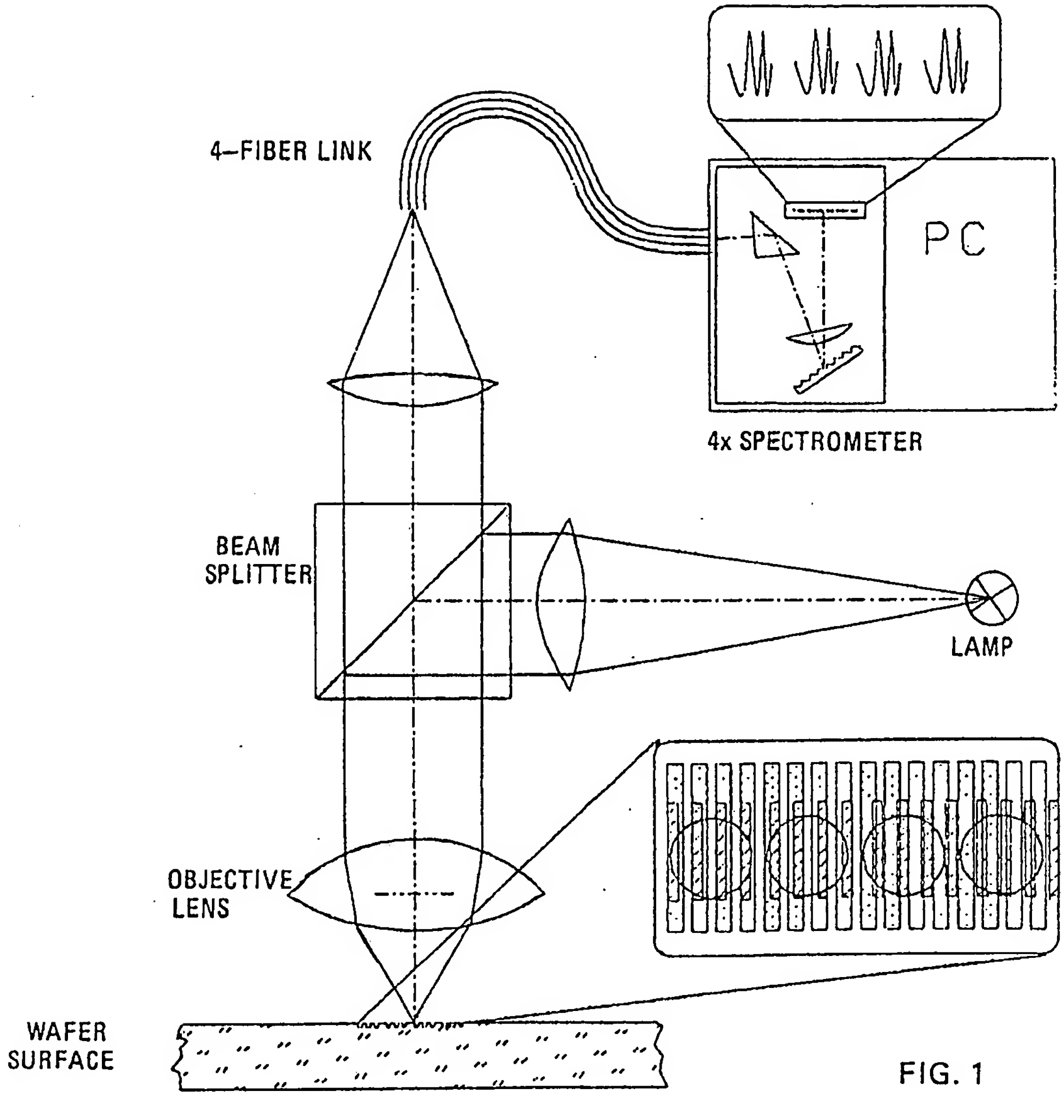
4-FIBER LINK
PC
4x SPECTROMETER
BEAM
SPLITTER
LAMP
OBJECTIVE
LENS
WAFER
SURFACE

FIG. 1

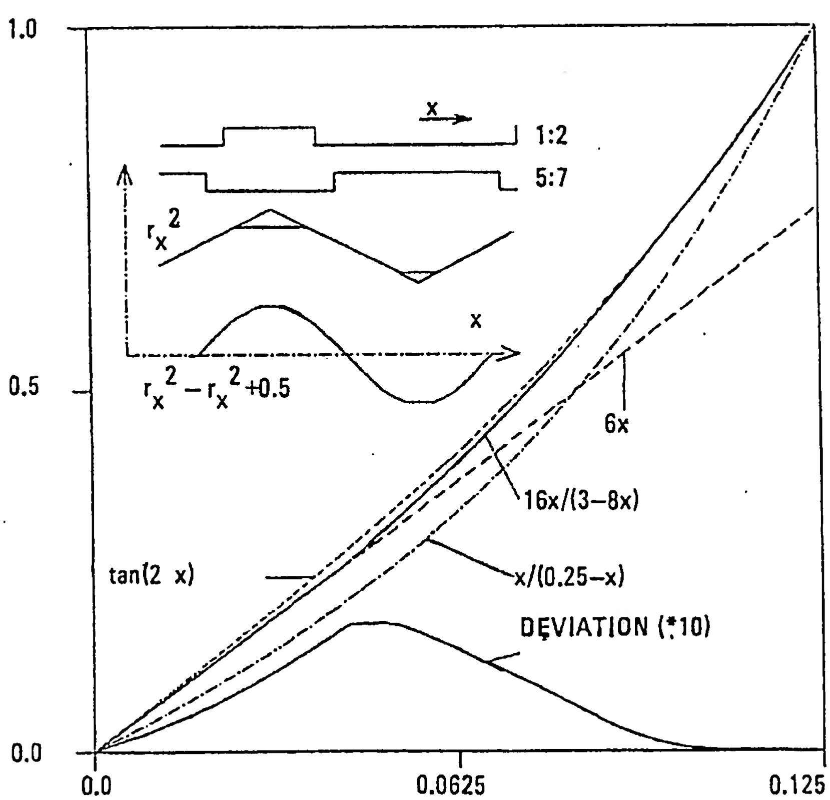
1.0
0.5
0.0
0.0
0.0625
0.125
x
1:2
5:7
r_x^2
x
$r_x^2 - r_x^2 + 0.5$
6x
16x/(3−8x)
tan(2 x)
x/(0.25−x)
DEVIATION (*10)

FIG. 2